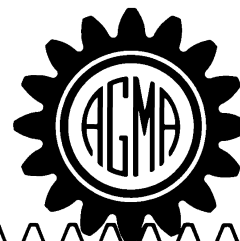


An Evaluation of FZG Micropitting Test Procedures and Results for the Crowned AGMA Test Gears

by: Dr. D.R. Houser, S. Shon and J. Harianto,
The Ohio State University

American Gear Manufacturers Association



TECHNICAL PAPER

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Dr. Donald R. Houser, Sam Shon, and Jonny Harianto, The Ohio State University

[The statements and opinions contained herein are those of the author and should not be construed as an official action or opinion of the American Gear Manufacturers Association.]

Abstract

This paper discusses the process of developing an understanding of the stresses and wear predictors using durability tests, with a focus on micropitting. The FVA Information Sheet No. 54/I-IV was used as an initial procedure, and later modified due to the higher contact stress levels predicted for the crowned AGMA test gears. A new procedure involving strain-gaging shafts on the FZG test machine was developed to produce better repeatability as well as more precise setting of load levels. Additionally, two oils were used and the micropitting wear amounts are compared. Topography measurements of tooth profiles, predictions of contact stresses and contact patterns, and comparisons of micropitting wear to these parameters as well as to flash temperatures and local film thickness are made.

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Introduction

This paper reports on the surface fatigue testing of gears that were manufactured as a part of the AGMA macro-pitting and tribology testing program [1]. The overall goal of this work is to develop models for predicting micropitting wear and to ascertain the appropriateness of the AGMA test gears for micropitting wear evaluation. As part of this goal, the study reported upon in this paper focuses on developing an understanding of the stresses and wear predictors using FZG durability tests. Since the focus is on micropitting, the first tests used the method described in FVA Information Sheet No. 54/I-IV [2]. Later, the procedure was modified to account for the much higher contact stress levels that are predicted for the heavily crowned and tip relieved AGMA test gears. This paper provides extensive analysis that includes detailed topography measurements of the tooth profiles, predictions of contact stresses and contact patterns, and discussions regarding factors that affect contact stresses, flash temperatures and local film thickness of the tested gears.

Testing Summary

The gears tested in this study are part of the second set of gears manufactured by AGMA and have serial numbers, 150 to 159. Since this study was a "learning experience" using the heavily modified AGMA test spur gears, the testing program was essentially a work in progress, with initial results causing methodologies to change as we progressed. Listed below is a summary of the tests that were performed with their results:

1. Staged loading at the FVA loading stages: Loads were at the low end of the range used by O'Connor [1], Hoeprich [3], and Buzydon and Cardis [4] so they were felt to be a reasonable starting point. Results showed micropitting wear and topography change even at the lowest loads, while at higher loads, macropitting oc-

curred. Also, a peculiar "T-shaped" contact pattern was observed.

2. Based on the above results, more detailed stress predictions were made, a more detailed study of the FZG loading procedure was performed, and the procedure for measuring tooth wear at each loading stage was refined.
3. Further tests were performed with staged loading, but at load levels that compensate for the increased contact stresses of the crowned gears. Micropitting still occurred, causing further concern about the predicted contact stresses.
4. Using revised loading stages, a higher viscosity, EP lubricant (ISO viscosity grade 220) was used as a replacement for the MIL L 23699 lubricant that was used in the previous tests. Micropitting wear was much less, but still occurred at the higher loading stages.

Tooth Topographies

The tooth geometry of the test gears is shown in Table 1 and the print specifications for leads and profiles are shown in Figs. 1 and 2. The lead specification of the test gear is straight with a tolerance of 0.005 mm.

It should be noted that the major "break" of the tip relief is about halfway between the highest point of single tooth contact and the tip of each tooth. Figs. 3 and 4 show lead and profile measurements on four teeth of each gear. Comparing the charts, the profiles and leads are made very close to the specification, however, the lead crown appears to be slightly greater than the specification. As will be shown later, the measured value of lead crown depends upon where on the tooth height the measurement is taken. During initial testing of the gears, a rather peculiar, T shaped contact pattern that is shown in Fig. 5 appeared, thus implying that the tooth topography was not as simple as expected from the original inspection charts. Therefore, more extensive measurements of the tooth topographies were performed.

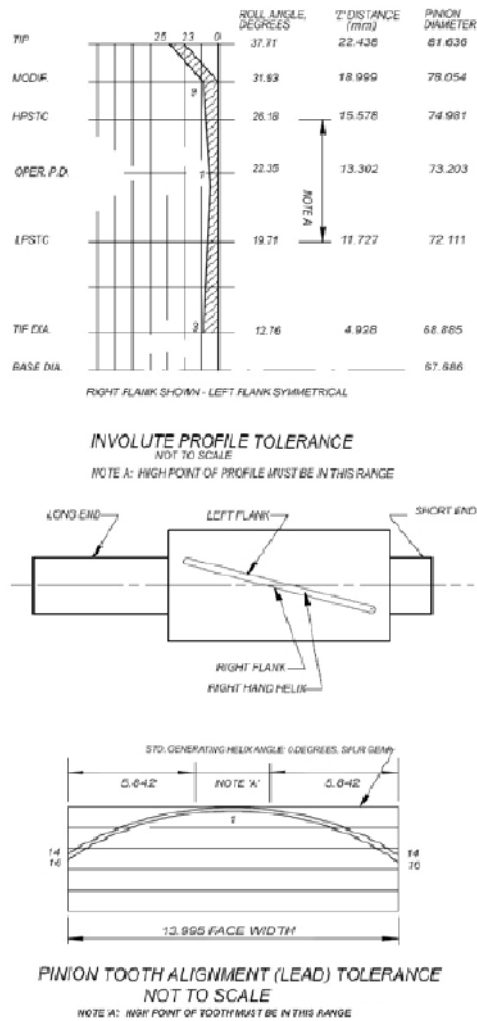


Figure 1: Profile and lead specifications for AGMA test pinion [5]

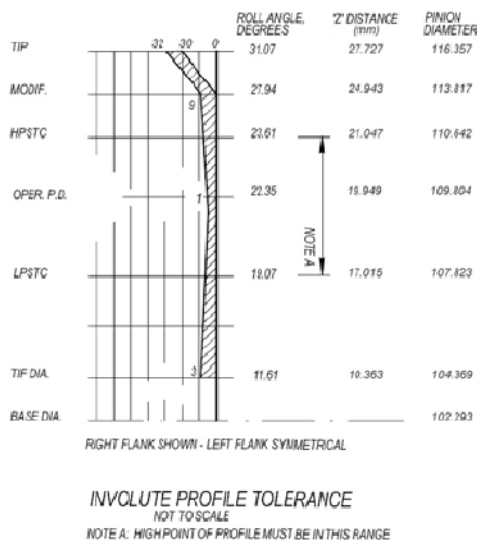


Figure 2: Profile specification for AGMA test gear [5]

Table 1: Geometry of AGMA Test Gear Sets [5]

Dimension	Unit	Pinion (Gear1)	Gear (Gear2)
Number of Teeth	-	20	30
Module	mm	3.62857	
Center Distance	mm	91.5	
Pressure Angle	deg	20	
Contact Ratio	-	1.58	
Face Width	mm	14	20
Outside Diameter	mm	81.64	116.36
Root Diameter	mm	64.338	99.162
Base Diameter	mm	68.194	102.293
Operating Pitch Diameter	mm	73.57	108.86
Standard Pitch Diameter (SPD)	mm	73.20	109.80
Tooth Thickness at SPD	mm	6.415	5.072
SAP Roll Angle	deg	9.280	12.111
EAP Roll Angle	deg	37.710	31.065

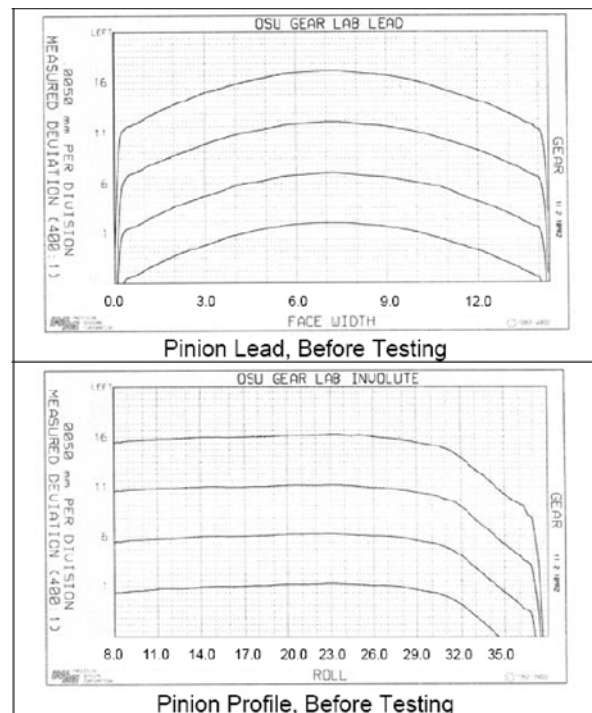


Figure 3: Standard Lead and Profile Measurements of the Pinion

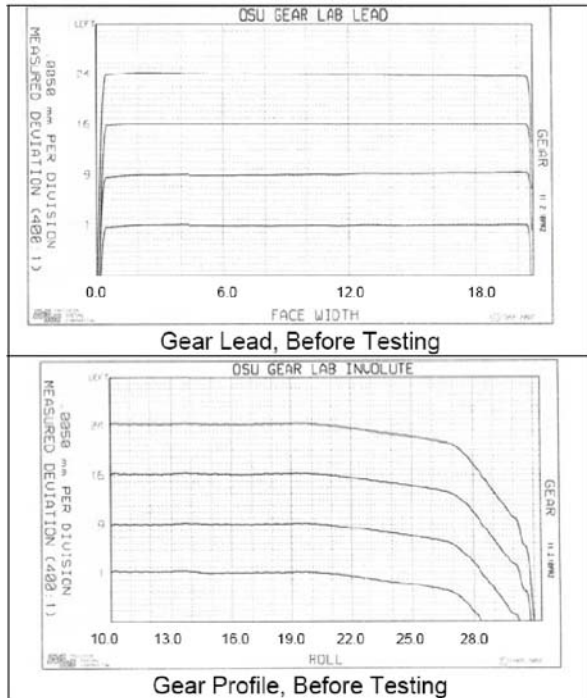


Figure 4: Standard Lead and Profile Measurements of the Gear

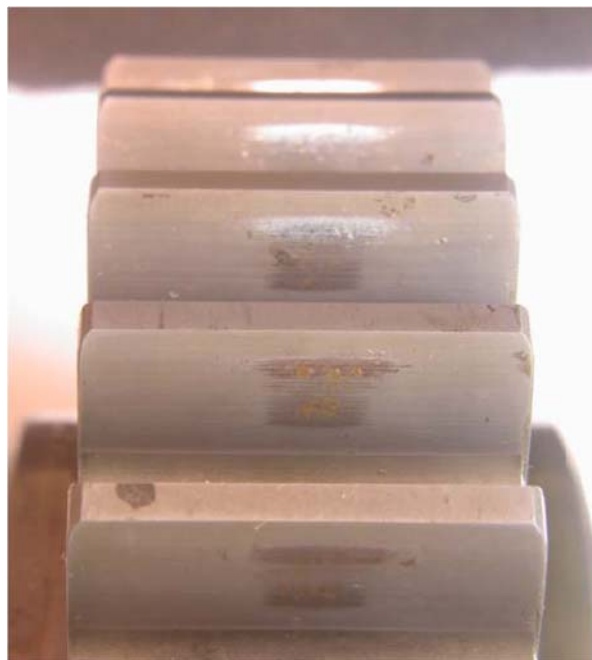
Fig. 6 shows such a set of measurements on one tooth, where 16 lead charts are shown on one graph and 16 profiles are shown on the other graph. The lead crown varies from 0.02 mm at the root to 0.06 mm at the tooth tip. This would imply that tool shift was used to obtain the crown and the amount of lead crown that occurs due to tool shift will be proportional to the sine of the pressure angle. In this case, the pressure angle varies from 9.1 degrees at the SAP to 33.3 degrees at the pinion tip so the ratio of the sines of these angles is almost exactly the ratio of the lead crowns observed in the measurements.

The leads and profiles of each set of the nine test pinions and gears are virtually the same within 0.0025 mm so it is fair to say that separate stress calculations for each gear set would not be needed. In the early testing, various versions of single and multiple profile and lead inspections were performed after each load stage. However, the final procedure that was chosen requires measurement of both the conventional single lead and profile on

four teeth spaced at roughly 90 degrees apart and the measurement of 16 leads and 16 profiles on one tooth. Teeth are numbered and marked so that the same teeth are measured after each stage.



Pinion



Gear

Figure 5: T-Shaped Contact Pattern on Pinion and Gear after Load Stage 5 (original loads)